Tree establishment in floodplain agroforestry practices

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ABSTRACT

The benefits of soil mounding, a cover crop, and various nursery stock types were evaluated for establishing pin and swamp white oaks in floodplain crop fields. The two stock types were 1-0 bareroot and large (3- and 5-gallon) container seedlings grown by the RPM™ method.

Basal diameter increment after three years was significantly greater ($P < 0.01$) for RPM™ seedlings than bareroot stock. Diameter growth was not significantly affected by soil mounding. Oak seedlings in redtop grass cover grew substantially more in diameter than oaks in the no redtop grass fields, though the differences were not significant ($P = 0.08$). RPM™ trees lost significantly more height during the first three years than bareroot seedlings. This was primarily a result of rabbit herbivory that caused shoot dieback on oak seedlings, and the inability of RPM™ sprouts to regain the lost height (e.g., as much as 2.0 to 3.0 m) in one summer. Rabbit herbivory on planted oaks, which occurred in the winter months of each year, was substantially greater in the no redtop grass than the redtop grass fields. Undamaged trees had the largest growth in basal diameter on average and had slightly positive height increment.

Third-year survival was high (> 94 percent) for RPM™ seedlings, which was significantly ($P < 0.01$) greater than survival of bareroot seedlings. Survival of oak seedlings was not significantly affected by soil mounding or cover crop treatments. However, an assessment of the survival of individual trees that were not damaged by rabbits indicated that redtop grass cover crop did significantly increase survival over that of trees grown with competing vegetation in the no redtop grass fields.

Introduction

Successful tree establishment is fundamental to implementing many of the agroforestry practices including (1) riparian buffer strips, (2) windbreaks, (3) alley cropping, and (4) silvopasture. In establishing these practices, landowners are often planting trees in pastures, crop fields or old fields, and they are commonly planting trees in riparian areas and floodplains. Planting trees in an agroforestry practice can be problematic in floodplains because of intense competition from herbaceous and woody plants, animal herbivory of seedlings, and flooding and saturated soils. In the Lower Missouri River basin and elsewhere throughout the Mississippi River Valley, landowners are interested in planting trees in bottomland agricultural fields, and they have a preference for planting oaks (*Quercus*), black walnut (*Juglans nigra* L.), pecans and hickories (*Carya*) for production of nuts (mast) and fine hardwood veneer and lumber. Regeneration of these species in bottomland agricultural fields is further complicated by their relatively slow juvenile growth, which is particularly a problem in regenerating the oaks.

Artificial regeneration and vegetation management is typically required to establish species such as oaks in floodplain environments. However, attempts to establish oak and other hard mast producing tree species in bottomland fields using artificial regeneration methods such as direct sowing acorns and planting bareroot seedlings have often failed. For example, in a survey of 4-year-old Wetland Reserve Program plantings in the Mississippi River floodplain, Schweitzer and Stanturf (1997) found that only nine percent of the total reforested land in 13 Mississippi counties met the Natural Resources Conservation Service requirement for at least 309 stems per ha in 3-year-old stands. Stanturf et al. (1998) attribute high rates of tree mortality and slow growth in bottomland plantings to (1) the use of poor quality seed or seedlings, (2) improper planting of seedlings and sowing of seed, (3) damage caused by deer, rabbits and mice, (4) drought, (5) severe competition, and (6) flooding. Loss of seedlings to flooding is higher when species are planted off-site in the floodplain, i.e., their flood tolerance is not matched with the microtopography and hydrologic regime of the site. Ultimately, slow-growing and damaged seedlings are easily overtopped by competing vegetation on these productive sites.

There are a number of stock type choices and cultural methods that may improve the survival and growth of planted seedlings in bottomlands. Landowners can take advantage of recent advances in nursery culture techniques that have made large (3- to 5-gallon) container-grown bottomland hardwood seedlings commercially available in the Midwest. It has been shown that seedlings with larger initial diameters and more fully-developed root systems have greater survival and growth rates (Johnson 1984; Kormanik et al. 1995; Schultz and Thompson 1997; Kormanik et al. 1998) and therefore may be more competitive on productive bottomlands. Second, cover crops can be planted to suppress weedy competition (Alley et al. 1999), which may increase both seedling survival and growth. Finally, soil mounding can improve seedling survival and growth by changing the microtopography, i.e., raising seedlings above flood waters or high water tables, removing excess surface water, decreasing bulk density, increasing aeration, and concentrating organic matter in the root zone (Fisher and Binkley 2000).

The purpose of this study is to test methods for regenerating pin oak and swamp white oak on former agricultural bottomlands along the Lower Missouri River. It evaluates how the cultural methods of planting trees in a soil mound and controlling competition with a cover crop can be used with different nursery seedling types to more successfully regenerate oak by improving its competitiveness when landowners are establishing trees in agricultural bottomlands. The field performance of a new nursery product, the RPM™ (Root Production Method) seedling is tested, and oak survival and growth is evaluated by soil mounding and cover crop treatment. RPM™ seedling performance is compared with traditional 1-0 bareroot seedlings. Oak regeneration success is related to vegetation competition, composition and structure under the different regeneration methods. This research focuses on solving the common problem of regenerating oaks in bottomlands and hence contributes to our ability to successfully establish trees in agroforestry practices in these areas.

Methods

The study is located on two conservation areas managed by the Missouri Department of Conservation: Smoky Waters (Sec. 5, T 44 N, R 9 W and Sec. 1, T 44 N, R 10 W; Cole County) and Plowboy Bend (Secs. 24 and 25, T 47 N, R 14 W; Moniteau County). Soils at the Plowboy Bend site were mapped as Sarpy Fine Sand (mixed, mesic, Typic Udipsamments); soils at the Smoky Waters site were mapped as Haynie Silt Loam (coarse-silty, mixed, superacitve, calcarious, mesic Mollic Udifluvents) and Leta Silty Clay (clayey over loamy, smectitic, mesic, Fluvaquentic Hapludolls). Map units of Haynie and Sarpy soils are classified as hydric, meaning that they are periodically saturated, ponded, or flooded with water during the growing season. Plowboy Bend is protected from the Missouri River by a levee; Smoky Waters is not. Smoky Waters has been flooded during June of 2000 and 2001 for periods ranging from several days to three weeks depending on location in the study fields. The study site at Plowboy Bend Conservation Area has not been flooded since the beginning of this research. Crops were previously grown in these fields until the fall of 1998. By the late summer of 1999, all study fields had a cover of herbaceous weeds and native plants.

Design

A split plot design was used in this study. Four 16.2 ha fields were equally divided between Smoky Waters and Plowboy Bend Conservation Areas. Each field was laid out as a square with a side being 402 m in length. A cover crop treatment was randomly assigned to each field at the two sites. The two cover crop treatments were (1) planting redtop grass (*Agrostis gigantea* L.) as a cover crop, or (2) permitting competing vegetation to develop naturally with the planted oak seedlings, i.e., the no cover crop treatment.

Soil mounding treatments (mounded or not) were randomly assigned across each field in groups of five rows each. Rows were spaced 9.1 m apart and oriented parallel to the Missouri River to ensure that soil mounds would not impound surface waters. Within each group of five rows, designated planting units were five rows wide and 45.7 m long and one combination of species and stock type was randomly assigned to each unit. Each planting unit contained 30 planting sites.

Stock types included 1-0 bareroot, and two classes of RPM™ seedlings. RPM™ is a trademark for the Root Production Method, an air root pruning process developed by Forrest Keeling Nursery in Elsberry, MO (Grossman et al. 2003). This nursery culture technique produces a large container-grown seedling that has a dense, fibrous root system. Trees are grown in 3- or 5-gallon containers and attain heights ≥ 1.5 m tall in one to two years in the nursery. In our study, RPM™ seedlings were either 1.5-year-old trees in 3-gallon pots, or 2-year-old trees in 5-gallon pots. Species tested are pin oak (*Quercus palustris* Muenchh.) and swamp white oak (*Quercus bicolor* Willd.).

Seedlings were planted on a spacing of 9.1 m within each row (119 trees per ha). Within a cover crop field, mounding, stock type and species treatments were replicated 4 times. Additional trees were planted at field edges to reforest the entire 16.2 ha.

Before establishing the experiment, soils were sampled to identify patterns in soil texture, hydrology and other physical properties that may influence plot layout. Soil texture and drainage regime, as evidenced by soil morphology, were determined to a depth of 1.2 m using an auger at both Plowboy Bend and Smoky Waters. Soils were sampled systematically across all fields, but microtopographic features such as ridges, old side channels and other shallow depressions were also sampled. Microtopography, soil texture and drainage did not vary substantially over the study areas, and differences in soil characteristics were spatially irregular, therefore soil condition was not a factor in the layout of the experimental units.

Study establishment

In mid-September of 1999, the redtop fields were worked with an offset disk, and soil mounds were constructed with a levee plow (AMCO LF6-824) on all fields. Soil mounds were 0.6 m in width at the top of the berm and 2.1 m at the base. After the soil settled, mounds were 30 to 38 cm above the natural ground elevation. In September, immediately following disking and soil mounding, redtop grass was sown at 3.6 kg per ha with a two-gang roller (Brillion) seeder.

For each oak species, approximately 1,200 seedlings of each stock type were planted in randomly located 30-tree plots, for a total of 7,362 trees over the entire study area. RPM^{TM} trees were planted in November of 1999 and the 1-0 bareroot seedlings were planted in the spring of 2000. At the time of planting, a slow release fertilizer (33-3-6) was applied to the ground surface around each seedling at an approximate rate of 30 g per tree. A 1.2 x 1.2 m woven plastic weed mat was placed around each seedling in the spring of 2000.

Measurements and analyses

Initial total height and basal stem diameter 2.5 cm above the ground were measured on all seedlings after planting and again at the end of each growing season. Seedling survival was determined each year and animal damage to seedlings was recorded. Animal damage consisted primarily of shoot clipping and girdling of main stems caused by eastern cottontail rabbits (*Sylvilagus floridanus* Allen) and white-tailed deer (*Odocoileus virginianus* Boddaert).

From June through August of 2000, ground layer vegetation was monitored using randomly-located paired 1-m^2 quadrats and 10-m x 20-m macroplots, permanently marked to facilitate remeasurement. Percent ground cover by species was determined on the quadrats and macroplots. Paired quadrats, one between seedlings within a planted row and one perpendicular to it between the rows, were used to quantify composition and abundance of competing vegetation within treatment plots. Three replications of mounding, stock type and species treatment combinations were sampled with paired quadrats, a total of 72-1 m^2 quadrats in each 16.2 ha field. Additionally, three macroplots were established in each 16.2-ha field to more thoroughly document total plant species diversity and successional patterns. Vertical structure of the ground flora was quantified at each quadrat location between rows using a density board to estimate percent cover of grasses, woody vegetation, forbs and total vegetation by 0.25-m height increments up to a height of 2.0 m (Hays et al. 1981).

Analysis of variance (ANOVA) was used to determine significant ($P < 0.05$) growth rate differences among species and stock type combinations between fields with and without redtop grass, and between mounded and non-mounded planting units. In this ANOVA, site was a random effect and cover crop treatment, mounding treatment, and species and stock type combinations were fixed effects. The significance of treatment effects on tree growth and survival were determined using their respective site interactions as error terms. For significant effects, orthogonal contrasts were used to compare mean differences. Logistic regression was used to develop models that predict survival based on seedling characteristics and management treatments.

Results and Discussion

Planting stock characteristics

Prior to planting, root volumes were determined by water displacement on a subsample of the trees (N=30 for each species and nursery stock type). Average root volumes for pin oak and swamp white oak bareroot seedlings were 26 ml and 33 ml, respectively. Average root volumes for 3-gallon RPM™ and 5-gallon RPM™ pin oak seedlings were 237 ml and 222 ml, respectively while those for swamp white oak 3-gallon RPM™ and 5-gallon RPM™ seedlings were 141 ml and 252 ml, respectively. Average root dry weight for bareroot seedlings was 18 g, which was substantially less than the average dry weight of 117 g for pin oak RPM™ root systems and 101 g for the roots of swamp white oak RPM™ seedlings. Shoot dry weight of bareroot seedlings averaged 9 g compared to 202 g for RPM™ pin oak seedlings and 138 g for swamp white oak. Initial basal diameters were similar for pin oak and swamp white oak bareroot seedlings, averaging 0.6 cm. RPM™ oak seedlings averaged 1.8 cm in basal diameter initially. Pin oak RPM™ seedlings were taller than swamp white oak RPM™ seedlings at the time of planting. Initially, heights averaged 2.20 m for pin oak RPM™ seedlings, and 1.80 m for swamp white oak RPM™ seedlings. In contrast, initial height of bareroot seedlings averaged 0.30 m, regardless of species.

Rabbit herbivory damage

Beginning in the first winter (2000/01), cottontail rabbits caused substantial damage to the planted oaks, and this damage has occurred every winter. The extent and severity of damage varied greatly between cover crop fields. In the no redtop fields, the composition and structure of winter cover provided by forbs promoted higher rabbit densities (7.4 rabbits per ha) than in the redtop grass fields (2.5 rabbits per ha) (Dugger et al. 2003). In the winter, the dead tops of forbs and clumps of Johnson grass remained somewhat erect providing cover that was 1.0 m tall. However, redtop grass matted down to 0.20 m and provided little hiding cover from predators such as hawks, owls and coyotes. Thus, rabbits were able to move freely across the no redtop grass fields causing damage to nearly all of the seedlings each winter. Rabbits clipped the shoots of all bareroot seedlings and severely girdled (more than half of the circumference of the stem) 90 percent or more of the RPM™ seedlings in the no redtop grass fields by the end of the second winter. In comparison, only eight percent of the bareroot seedlings and 26 percent of RPM™ seedlings in the redtop grass field at Plowboy Bend Conservation Area had herbivory damage from rabbits. Similarly, but to a lesser extent, 12 percent of the bareroot seedlings and 23 percent of the RPM™ seedlings in the redtop grass field at Smoky Waters Conservation Area were damage free. Moreover, the severity of damage to RPM™ trees in redtop grass fields was less than in the no redtop grass fields. These differences in winter habitat between the cover crop treatments affected rabbit densities and movements, which in turn, contributed to the significant differences in oak seedling basal diameter and height increment between the cover crop treatments.

Basal diameter increment

After three years, RPM™ seedlings grew significantly more ($P < 0.01$) in basal diameter than bareroot seedlings, regardless of species. The average basal diameter of all RPM™ oak seedlings increased 0.8 cm in the first three years, whereas bareroot seedlings increased only 0.3 cm (Figure 1). There was no significant difference ($P = 0.34$) in basal diameter increment between the 3- and the 5-gallon RPM™ seedling. The basal diameter of pin oak 5-gallon RPM™ seedlings increased the most during the first three years, averaging 1.0 cm of new growth. Basal diameter increment was least (0.1 cm in three years) for pin oak bareroot seedlings. The above analysis includes rabbit damaged and undamaged trees. By removing the rabbit damaged trees, average basal diameter increment was 1.6 cm for RPM™ seedlings and 0.2 cm for bareroot trees.

Planting bareroot or RPM™ oak seedlings in mounded soil did not significantly ($P = 0.73$) improve basal diameter growth during the first three years at either Smoky Waters or Plowboy Bend Conservation Areas. Basal diameter increment of all trees combined was substantially larger in redtop grass fields (1.4 cm) compared to no redtop grass fields (0.2 cm), however, no significant differences can be reported as yet ($P = 0.08$). For undamaged trees, average basal diameter increment was 1.6 cm for RPM™ seedlings in redtop grass fields and 0.4 cm in no redtop grass fields, while the basal diameter of bareroot seedlings increased by 0.3 cm in redtop grass but decreased by 0.2 cm in no redtop grass fields.

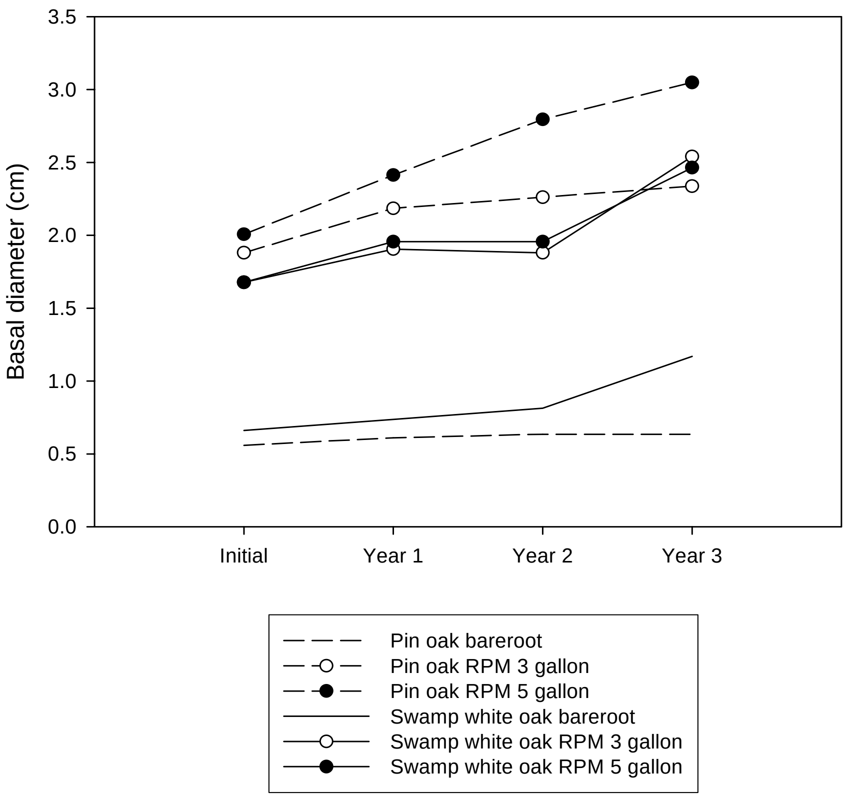

Figure 1. Average initial and annual basal diameter (measured 2.5 cm above the ground) of oak seedlings by species and nursery stock type.

Height increment

Average height increment after three years was negative for most species and nursery stock types because cottontail rabbits caused extensive damage by girdling the stems of RPM^{TM} seedlings, or by clipping the shoots of bareroot seedlings at ground-level, which caused shoot dieback and loss of height (Figure 2). Most rabbit-damaged RPM^{TM} trees survived and produced a clump of basal sprouts, but their annual shoot growth was not enough to recover the height lost due to death of the parent stem. In subsequent years, the sprouts from RPM^{TM} and bareroot seedlings were subject to shoot clipping by rabbits during the winter months.

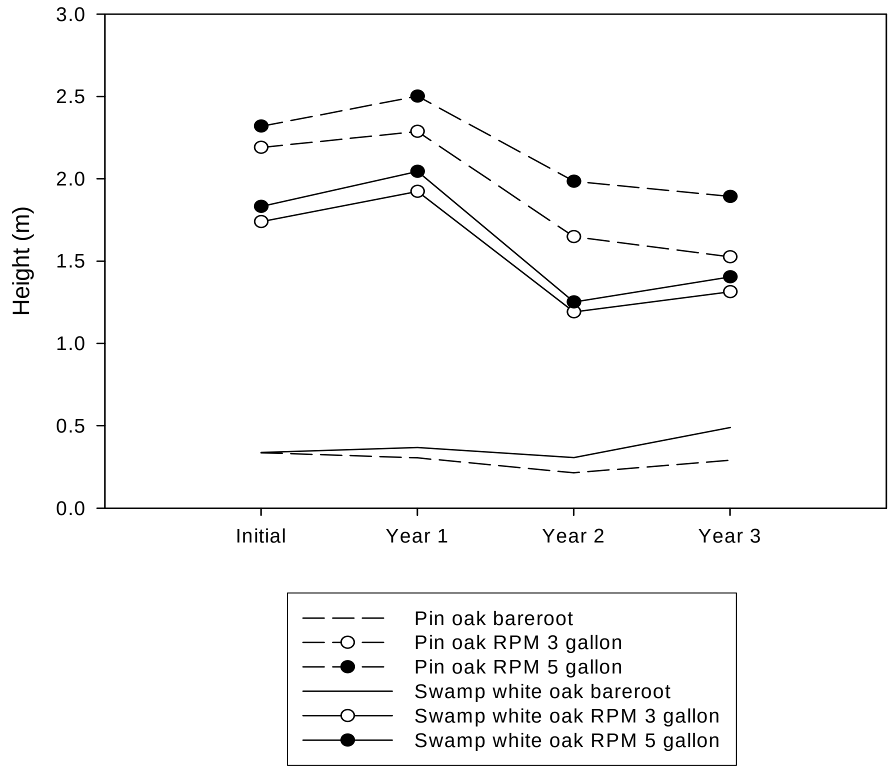

Figure 2. Average initial and annual height of oak seedlings by species and nursery stock type.

Three-year height increment was significantly less ($P < 0.01$) for RPM™ seedlings than bareroot. For bareroot seedlings that had been shoot-clipped by rabbits, annual sprout shoot growth came close to, or slightly exceeded the initial height, resulting in small negative or positive increments in height. Height increment averaged -0.03 m for pin oak bareroot seedlings and +0.12 m for swamp white oak bareroot seedlings. In contrast, net height increment was much lower in RPM™ trees because rabbit girdling occurred in the lower 0.30 m of the stem, the tall shoots died back to near ground-level, annual sprout shoot growth was not enough to recover the original height, and trees were often repeatedly damaged by rabbits each winter. Three-year height increment averaged -0.50 m for the RPM™ seedlings. Despite rabbit browsing, RPM™ trees remained taller than bareroot seedlings three years after planting. For undamaged trees, average height increment was 0.10 m for bareroot and RPM™ seedlings growing in redtop grass cover, but averaged -0.53 m for RPM™ and -0.13 m for bareroot seedlings in no redtop grass fields. Three-year height increment was significantly higher ($P = 0.02$) for oak seedlings growing in the redtop grass fields than those trees competing with natural vegetation in the no redtop grass fields. There may be less light competition in the redtop grass fields during the growing season and fewer rabbits in the redtop grass fields during the winter months.

Competing vegetation

Redtop grass, a cool season grass that grows to a height of 0.40 m to 0.60 m, was effective in reducing the amount of cover of other vegetation. In the redtop grass fields, redtop grass accounted for about 70 percent or more of the total vegetative cover by the second growing season, and during each summer there was little vegetative cover above 0.50 to 0.75 m. The no redtop grass fields were dominated by forb and vine species such as horseweed (*Conyza canadensis* L.), tall morningglory (*Ipomoea purpurea* (L.) Roth), redroot pigweed (*Amaranthus retroflexus* L.) and cutleaf primrose (*Oenothera laciniata* Hill). The only grass in these fields was Johnsongrass (*Sorghum halepense* (L.) Pers.), which averaged 13 percent ground cover. The forb-dominated vegetation provided substantial cover (i.e., 17 to 22 percent) at 1.00 to 1.25 m height and some vegetation reached heights above 2.00 m during the summer.

Average third-year heights of bareroot seedlings ranged from 0.30 m for pin oak to 0.50 m for swamp white oak. Therefore, many of the bareroot seedlings in the no redtop fields were in the shade of the herbaceous canopy. In the shorter vegetation of the redtop grass fields, bareroot seedlings were more likely to successfully compete for light in the mid to upper strata of the redtop-dominated herbaceous canopy. Taller RPM™ seedlings (e.g., third-year heights averaging 1.3 to 1.7 m) were more competitive than the bareroot seedlings because they were either in, or above the herbaceous canopy in all fields, especially in the redtop grass fields.

Survival

Survival of oak RPM™ seedlings remained high (i.e., > 94 percent) during the first three years (Figure 3), while survival of bareroot seedlings continued to decline for both swamp white oak and pin oak. After three years in the field, swamp white oak bareroot survival averaged 76 percent, and survival was lowest (54 percent) for pin oak bareroot seedlings. The ANOVA results indicated that soil mounding treatment had no significant effect ($P = 0.96$) on oak seedling survival. There was no significant effect ($P = 0.48$) of cover crop treatment on oak seedling survival. While, survival of RPM™ oak seedlings was significantly higher ($P < 0.01$) than that of bareroot seedlings, there was no significant difference ($P = 0.24$) between 3- and 5-gallon RPM™ seedlings, nor between swamp white oak and pin oak RPM™ seedlings ($P = 0.87$). Survival of swamp white oak bareroot seedlings was significantly higher ($P < 0.01$) than pin oak bareroot seedlings.

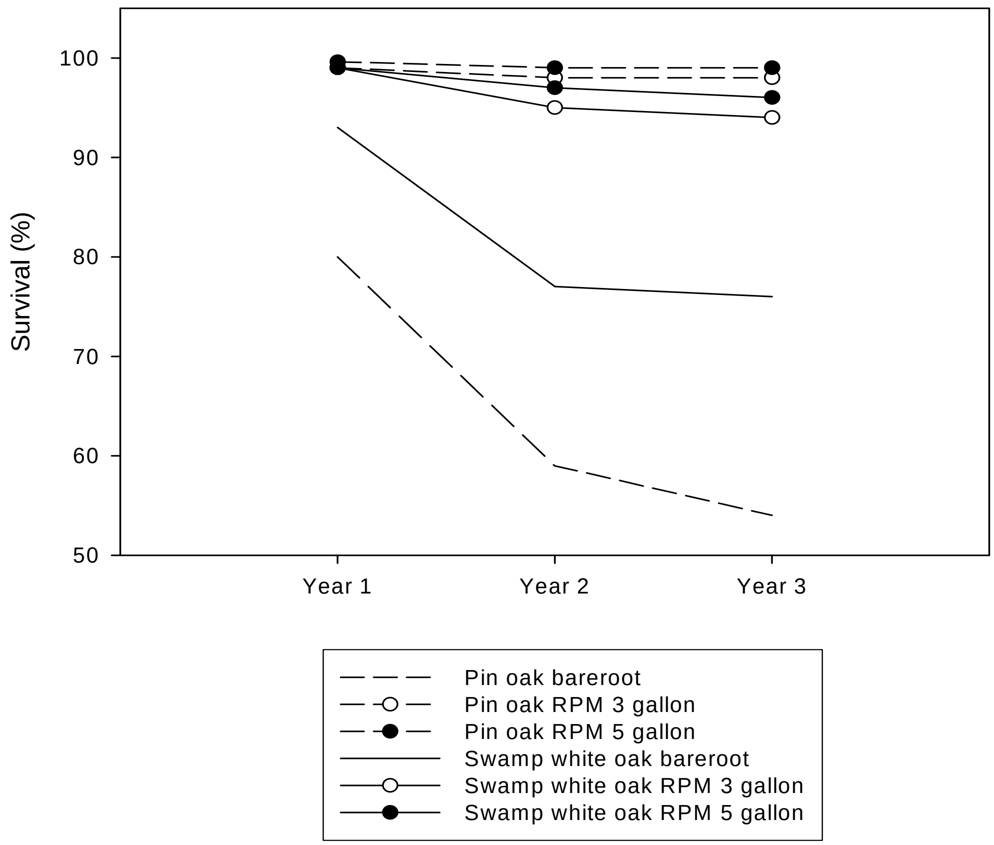

Figure 3. Annual survival of oak seedlings by species and nursery stock type.

To remove the confounding effect that rabbit damage had on seedling survival, seedlings that had been stem girdled or shoot clipped by rabbits were eliminated from a logistic regression analysis of oak seedling survival. The probability of an oak seedling dying in the first three years was estimated using models that included various combinations of initial seedling height and basal diameter, species, nursery stock type, and cover crop treatment. Based on a comparison of ΔAIC and w_i statistics for each model considered (Burnham and Anderson 2002), the following model was one of the best for predicting the probability of pin oak seedling mortality at Smoky Waters Conservation Area (ΔAIC = 0; $w_i = 0.444$):

(1) $P = (1+\exp(-(1.1227 + 0.8732*ID - 2.3099*IH + 1.3922*SPECIES + 2.0151*STOCK - 2.8932*COVER)))^{-1}$,

where P= the probability of mortality during the first three years; ID = initial basal diameter (cm); IH = initial height (m); SPECIES = 1 for pin oak, 0 for swamp white oak; STOCK = 1 for bareroot seedlings and 0 for RPM™; COVER = 1 for redtop grass and 0 for no redtop grass cover.

Similar models were identified for swamp white oak, and for oak reproduction at Plowboy Bend Conservation Area.

The probability of mortality in the first three years declined with increasing initial height and basal diameter of oak seedlings (Figure 4). For seedlings of a given initial height and basal diameter, the probability of mortality was much lower for seedlings growing in a redtop grass cover than it was for seedlings competing with forb-dominated vegetation that colonized these crop fields. For example, the probability that a pin oak seedling that is 0.30 m tall and 0.5 cm in basal diameter when planted dies during the first three years is estimated to be 80 percent if the seedling is in a redtop grass cover, but as many as 97 percent of the pin oak seedlings are expected to die when they are competing with natural

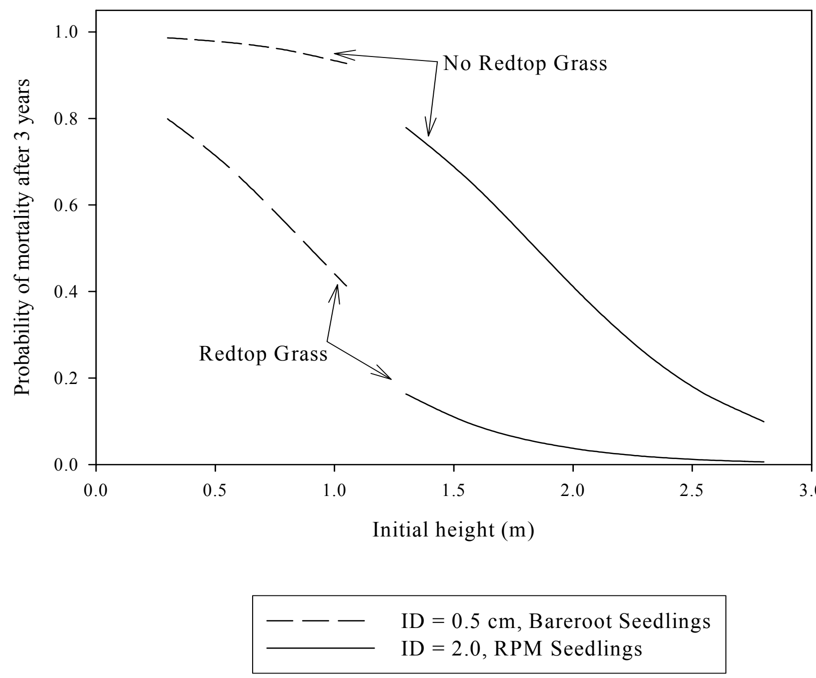

Figure 4. The probability of mortality after three years in relation to initial seedling height of pin oak seedlings planted with a cover crop of redtop grass or in natural vegetation that develops in abandoned bottomland cropfields at Smoky Waters Conservation Area [based on equation (1)]. In this illustration, mortality is estimated for oak seedlings with ID (initial basal diameter) = 0.5 cm (representative of the average pin oak bareroot seedling in our study); and for seedlings with ID = 2.0 cm (representative of the average RPM™ pin oak in our study).

herbaceous vegetation that colonizes bottomland crop fields. If a pin oak seedling is 2.00 m tall and 2.0 cm in basal diameter when planted, the probability of mortality in the first three years declines to three percent for trees in a redtop grass cover, and to 35 percent for trees competing with natural vegetation. Similar trends were observed for swamp white oak seedlings. This benefit of a cover crop on seedling survival may be related to the ability of redtop grass to control other competing vegetation, which often grows much taller than redtop grass and competes more with oak reproduction for light.

Summary/Conclusions

Stem girdling and shoot clipping by rabbits that occurred during the winter months each year varied by cover crop treatment and this had a profound effect on seedling height by the third year. Large container stock (i.e., the RPM™ seedlings) had significantly greater survival and basal diameter growth than bareroot seedlings after three years. Basal diameter growth was greater for undamaged seedlings than for those that had been girdled and shoot clipped by rabbits. Three-year height increment for RPM™ seedlings was negative and significantly less than that of bareroot seedlings largely due to the loss of initial height from rabbit herbivory on oak seedlings. Undamaged seedlings had slight increases in height during the first three years. The initially shorter bareroot seedlings that were shoot clipped by rabbits were able to recover most of the lost height growth in a single season through production of basal sprouts, whereas RPM™ sprouts were not able to grow enough in a summer to regain the lost 1.5 to 2.0 m in height. There was no difference in growth or survival to-date between the 3- and 5-gallon RPM™ trees.

A redtop grass cover crop benefited oak regeneration by controlling competing vegetation and reducing rabbit damage. Redtop grass was effective in preventing the development of much of the forb and woody growth that normally forms on abandoned bottomland crop fields, thereby reducing competition for light between oak seedlings and other vegetation. Redtop grass also formed a low growing ground cover that provided little winter habitat for cottontail rabbits, thus reducing herbivory damage to oak seedlings. In the no redtop grass fields, rabbits shoot clipped or severely girdled the stems of practically every oak seedling. In the redtop grass fields, many trees were never damaged by rabbits during the three years, and damage on those that were was much less severe than it was for seedlings in the no redtop grass fields. Three-year height increment was significantly less for RPM™ seedlings than for bareroot seedlings due largely to the loss of initial height from rabbit girdling. Although, height increment of undamaged RPM™ seedlings growing in redtop grass cover was positive and similar to the growth of bareroot trees. Three-year basal diameter increment was substantially larger for oak seedlings in redtop grass fields than no redtop grass fields, but the difference was not yet significant.

After three years, soil mounding did not improve height and diameter growth, or survival of oak seedlings at both sites where soils are loamy and fairly well drained. Despite flooding in June, two out of the three years at Smoky Waters, soil mounding does not appear to be needed for oak regeneration. Use of soil mounding to improve drainage, reduce flooding effects on trees and improved soil environments for root growth may be worthwhile on more poorly drained, clayey soils, but this remains to be tested.

Planting seedlings of large size in a redtop grass ground cover appears to be a successful formula for establishing hard mast trees in floodplain agroforests.

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